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# Recording Thera Santorini's subterranean landscapes: A noninvasive approach to the investigation of cave use strategies in insular environments [AQ1]

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[AQ0]

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## ABSTRACT

This paper investigates cave use strategies in insular environments, focusing on a case study from Santorini (Thera) island in Greece. The paper has a two-fold aim to propose and test a methodological framework for noninvasive archaeological evaluation of cave sites and to explore the ways that people, not only on Santorini, but also on similar small islands, have engaged with caves through time. Santorini is famous today as a holiday destination; however, a large part of the island's historic landscape has disappeared. This is due to the Bronze Age volcanic eruption that covered the majority of the island with a thick layer of tuff and pumice, as well as intensive building and agricultural activity in the second half of the twentieth century, all of which have dramatically transformed the island's natural environment. Today, our accounts of the island's prehistory come from the extraordinary preservation of the Akrotiri site, and considerable knowledge gained from other locations, about the role that the island played diachronically in the history of the Aegean. We are, however, still missing valuable information about the relationship between the island's inhabitants and their environment.

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**Keywords:** Archaeological cave survey ; paperless mapping ; Aegean Bronze Age ; Medieval Aegean ; cave archaeology

## Introduction

In the last few years, several archaeological and ethnographic projects in the Mediterranean have explored the human use of caves in diachronic perspective (for a review see Trimmis 2019). Most notably, the Pelion Mountain Project, focused on human use of caves in the mountain range of Eastern Thessaly in Greece (Andreasen et al. 2017) and the Seulo Caves Project that investigated human uses of caves in the territory of Seulo, central Sardinia (see Skeates 2011) are good examples. These projects, however, focus on the use of caves in a large mainland territory or on a large island. In contrast, our research investigates cave use strategies on one of the smaller Aegean islands, but one with evidence for diachronic occupation and a rich cultural history. The ongoing research and preservation project of cave sites in the Cyclades by the Ephoreia of Palaeoanthropology and Speleology has added new and complementary evidence for the role and importance of caves in the insular environment of the central Aegean islands (Mavridis 2018a; Mavridis, Tankosić, and Kotsonas 2018).

Santorini (Thera) Island (Figure 1) is located in the southern Aegean Sea and is part of the Cyclades complex of islands. The island is the most active volcanic center of the Hellenic volcanic island arc, where the last major eruption took place in 1950 (Perissoratis 1995, 37). Santorini's geology comprises metamorphic formations of the Attico-Cycladic massif. These consist of gneisses, schists, marble and limestone, and volcanic rock, including tuff, pumice, and basalt of the Late Pliocene-Quaternary Age (Perissoratis 1995, 38). Santorini is technically a complex of islands ar-

ranged in a ring around a flooded caldera (Nomikou et al. 2016). This paper focuses on the main island of Santorini and not on the smaller neighboring islands of Aspro, Therassia, Palea and Nea Kammeni. The volcanic material covers the majority of the island today and only a small part consists of metamorphic formations in the areas of Mesa Vouno, Profitis Ilias, and Gavrilos. It is worth mentioning that Santorini is actually a volcanic complex of both active and non-active volcanoes (Perissoratis 1995). Today the active parts are the volcanoes of Nea Kammeni at the center of the Caldera and Columbo, a submerged volcano northwest of the main island. Santorini has been the focus of significant volcanological research, mainly because of the Bronze Age (around 3500 BP) explosive eruption that buried the prehistoric town of Akrotiri. As a result of this interest, Santorini is one of the most studied European volcanoes (for a review of the island's geomorphology and previous studies, see Dominey-Howes and Minos-Minopoulos 2004 and Nomikou et al. 2016). Extensive work has been carried out on the island due to the centrality of the island's volcanoes in understanding the geology and seismic activity of the Eastern Mediterranean, and the corresponding importance of the Akrotiri archaeological site for understanding the dynamics of the Bronze Age Mediterranean. Despite this work, research on the island has almost exclusively focused on open air sites, with only minimal research on the island's caves.

Figure 1. Top left: satellite image of Santorini. The limited areas that are undisturbed from cultivation and building development are visible. Bottom left: a simplified geological map of Santorini. Right: The locations of the sites that are referred in this paper (with triangles indicating prehistoric sites; squares Classical/Roman; diamonds Medieval/Venetian; and circles for cave sites). 1. Akrotiri 2. Archangellos 3. Raos 4. Chalarovounia 5. Ftelos 6. Akrotiri fortress 7. Emporio fortress 8. Pyrgos 9. Skaros 10. Oia 11. Ancient Thera 12. Rockshleter at Kokkini 13. Vlychada 14 Gavrilos 15. Panayia Katifiani 16. Klasoysterna 17. Agios Georgios Katifio 18. Zoodochos Pigi 2 19. Zoodochos Pigi 1 20. Ancient Thera 21. Foinikia 1 22. Foinikia 2 23. Foinikia 3.

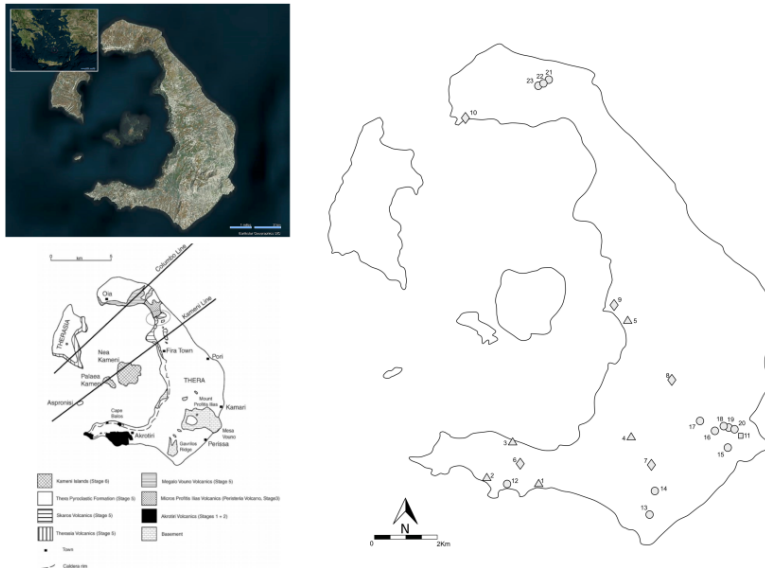


Figure 2. (a) A view of the entrance of the rock shelter at Ancient Thera. (b) The chapel at Zoodochos Pigi 1. (d and e) Different views of the drystack wall at Zoodochos Pigi 2. **AQ9**



In addition to Akrotiri, Santorini has other important archaeological sites that cover a wide spectrum of archaeological and historical periods; Raos, Chalarovounia, and Archangelos, for example, represent prehistory; Ancient Thera, the classical and late antiquity period; while the Venetian fortresses, of Emporio, Pyrgos, Akrotiri, Skaros and Oia are characteristic examples of fortified towns of the later medieval Eastern Mediterranean (for an overview see contributions in Danezis 2001).

All of these extraordinary sites on Santorini, seem “out of context” mainly because the landscape on which they were built is now gone as a result of: 1) the prehistoric landscape being buried below several meters of tuff and pumice, making archaeological survey on the paleosols extremely difficult (see Aston and Hardy 1990; Vlachopoulos and Zorzos 2014); and 2) the frantic building and agricultural activity of the twentieth century have contributed much to the general reforming of the island’s landscape. Today, only six areas of the island are still relatively untouched by building activities; the area of Foinikia–Columbo in the north, the limestone massif of Mesa Vouno, part of the Profitis Ilias massif, the southeastern part of Gavrilos hill, the area around the Akrotiri archaeological site (mainly the Mesa Vouno area) and the area of Archangellos, southwest of the modern village of Akrotiri. As a result of these issues, what we know about the relationships of past inhabitants on the island with their surroundings is minimal. This knowledge comes mainly from the Akrotiri frescos and other archaeological datasets, from which we can only address limited questions about animal herding, agriculture, or water management. Aston and Hardy (1990) have also used mathematical models of settlement patterns on Santorini and land use developed on Milos, but today these models are outdated and of little value. As such, Santorini’s caves seem to represent an ideal case study, given that their protective environment might have been less affected by volcanic materials and modern activities.

## Previous research, aims and objectives of cave research on Santorini

The Hellenic Speleological Society (HSS) first visited Santorini’s caves during two expeditions in 1952 and 1970 with reports having been published in Volumes II and X of the “Bulletin of the HSS”, respectively. The 1952 expedition also visited the cave of Zoodochos Pigi on Profitis Ilias Mountain, the main limestone occurrence on the island. In 1970, three more caves were recorded on the west side of the same mountain and two relatively large caves (around 60 m in length) in lava formations in the Foinikia area, close to Cape Columbo in the northern part of the island. In 2001 the Speleological Group of Bologna (Gruppo Speleologico Bolognese - GSB), from Italy, visited the island and explored two horizontal caves at Profitis Ilias mountain, Zoodochos Pigi (ZP) 1 and 2 (ZP1 was the same cave that had been visited by the HSS in 1952). The outcomes of the Italian expedition have been published in GSB’s bulletin “Sottoterra” (Demaria 2001). Finally, caves with archaeological finds from the Classical and Roman periods have been recorded in the area, inside the boundaries of the Ancient Thera archaeological site, such as the cavity of Hermes and Hercules’ sanctuary, as well as the cavity of Poseidon—Asphaleiou (See Ingelese (2008) for a detailed account on classical period cults in Ancient Thera caves).

For our research we aimed to revisit the caves that had been previously explored and also to search for new sites, with the goal of establishing the first cave inventory of Santorini Island. The current project was formulated following the hypothesis that the caves of Santorini may hold valuable information about the archaeology of the island before the Bronze Age eruption and more generally about the diachronic use of caves in the Aegean from an archaeological-ethnographic perspective. Another aim was to test the authors' proposed cave survey methodology in the field to see if a standardized framework for archaeological surveys in caves could improve the interpretation of archaeological evidence (for the proposed methodology see Heeb 2014 and Trimmis 2018).

To achieve our aims, we set three objectives: 1) to walk the areas of the island where natural cavities were known from previous speleological expeditions in the areas of Mesa Vouno, Profitis Ilias, Gavrilos, Foinikia, and Archangelos/Kokkino Vouno to locate, record, and noninvasively evaluate their archaeological potential; 2) identify cave use strategies on the island based on surface artifacts and/or structures; and 3) spatially and statistically analyze the available evidence to identify how Santorini's communities engaged with caves and their natural environment throughout the island's history.

## Recording the archaeological potential of Santorini's caves

### Methodological framework

For the research on Santorini we selected the total research approach for archaeological surveys, as described by Banning (2002). Based on this approach, the overall number of finds per area (generally arbitrarily defined) is recorded rather than just a sample. For cave surveys we did not have to deal with the issue of defining the research area boundaries, since caves are a confined micro-landscape, as noted by Moyes and Awe (1998).

The standardized framework that we proposed for the Santorini noninvasive archaeological survey can be organized into three main methodological steps:

1. Recording of the cave: this involved accurately identifying the location of the cave entrance with either a Global Navigation Satellite System—Global Positioning System (GNSS-GPS) or an Electronic Distance Measuring (EDM) device. We then described and photographed the cave's entrance and interior (including its dimensions, orientation, and area); ~~a~~ noninvasively described and evaluated cave deposits following protocols outlined by Dinnis, ~~et al.~~ Davies, and Chamberlain (2010) and Holderness et al. (Holderness et al. (2006)2006) for a standardized framework for field archaeological prospection of caves. The Holderness et al. (2006) protocol records, in a standardized format, the cave location, setting, geomorphology, deposits, conservation status, and the presence or absence of archaeological finds. However, the locations of the finds are not annotated. Dinnis, Davies, and Chamberlain (2010) suggest a methodological approach that assesses the deposit cave sites and evaluates their archaeological potential. Neither the Holderness et al. (2006) nor Dinnis, ~~et al.~~ Davies, and Chamberlain (2010) approach involves excavation or coring. The assessment is based on visual description of the deposits, their formation, inclination, thickness, and the presence or absence of factors that may showcase heavy bioturbation/truncation. As an example, based on this approach, thick, flat, deposits that are undisturbed by bioturbation and water flows have a higher potential for intact archaeological evidence compared to thin, "washed" deposits with evidence of significant bioturbation (e.g., water-flows, guano accumulation) (Table b—Figure 1). Finally, all related information was recorded on a form specifically designed for this research.
2. Surveying the cave: The mapping of the cave interior was done using a Leica DistoX2 following the paperless mapping methodology proposed by Heeb (2014) and adapted for use in archaeological cave sites by Trimmis (2013, 2015b, 2018). Using this methodology, the archaeological evidence spotted *in situ* is recorded without moving or collecting any artifacts (such as surface pottery or standing structures). This is feasible thanks to the taphonomic conditions of the majority of Greek caves—relatively low bioturbation, minimal water flow, and the usual presence of surface finds. Heeb's technique uses a retrofitted Leica distance meter, that incorporates a digital compass/clinometer (DistoX2, the current model) to send measurements through Bluetooth to a PDA (Personal Digital Assistant) computer running PocketTopo software (see Trimmis 2018 on



DistoX2 applications in archaeology). As such, the researcher can collect the data and draw the basic map inside the cave in real time. From PocketTopo, the data can be exported for analysis and presentation in .dxf format to any GIS or CAD software using Therion cave survey software for the conversion (see Trimmis 2018, 402 for a detailed presentation). All surface features, geological and anthropogenic, must be recorded and annotated on the map. Afterwards, the cave area is separated into discovery units (DUs) with boundaries that follow the natural formation of the cave. DUs (Gregory et al. 2019) do not have predetermined dimensions, nor do they follow a pre-established grid. Their defining borders usually follow landscape features and modern field boundaries. DUs in our methodological framework are an elastic tool that can be adapted to the varying needs of different localities. As with excavation units, DUs are interpretational and designed to record past activities in the field. Any surface finds should then be recorded and counted *in situ* by cave-walkers and then annotated on the cave map.

3. Analysis and presentation of the datasets: Data is then exported from Therion to any GIS software for further analysis and presentation (see also Trimmis 2018 for an analytic presentation). Adobe illustrator or CAD software are used for the final presentation of the map.

The application of ‘discovery units’ for the survey in the Santorini caves might sound dated in the framework of current approaches to archaeological survey in Mediterranean landscapes. In fact, in cave sites where space is limited, field walkers often have to work in absolute darkness and chambers are followed by narrow passages. This makes it difficult for a survey to be conducted following the standardized ‘grid and sample’ system that dominates archaeological survey of open air sites. For example, In Brady’s (2012) edited volume on Mayan ritual cave use, three contributions present cave survey research (Ishihara-Brito and Guerra 2012, 51–60; Moyes 2002, 95–110), and do not follow a standardized grid survey methodology for the recording of finds. In the Pelion Mountain and Kastoria projects (see Andreasen et al. 2017 and Trimmis 2013, respectively), archaeological survey methodology counted caves as one unified enclosed landscape. On Santorini, following the DU approach and by assigning each cave component—passages, chambers, niches, entrance area—to a different team member, we aimed to identify the spatial correlation between features and finds in their respective locations and manage the effects of cave survey on our team members. As previously presented by Moyes and Awe (1998), the darkness, high humidity, radon concentrations and tight spaces in these cave environments can cause survey team members to experience fatigue, disorientation, muscular pain, and discomfort, all of which negatively impact team wellbeing and the quality of the survey. With the use of DUs, the cave components were arbitrarily delimited by the team leader prior to the survey. The team members then counted the surface pottery using an analogue tally counter. Pottery concentrations and/or diagnostic sherds together with other special finds, like grinding stones or tools, were annotated with reflective tags. The mapping team **also** surveyed the reflective tags and annotated the archaeological information on the cave plan. Important and diagnostic finds were photographed *in situ*. This clear organization of the survey space into meaningful units that followed the cave layout helped the team to survey both the caves and finds with high efficiency and speed. Finds in the different chambers and passages of the caves were more easily correlated with one another and assessed, and significant concentrations in particular areas were interpreted more efficiently.

Additionally, we also made an account of modern and contemporary uses of the caves and the potential scientific importance of the sites for other fields, such as speleothem studies, paleontology, and volcanology. Finally, an account of the conservation status of each cave was made, with comments on the potential risks that the caves may face.

## The caves

To-date our research has recorded 12 cave sites (Table 2). These caves were mainly located on the Foinikia Lava formations (3 caves) and the Mesa Vouno/Profitis Ilias Massif (6 caves). One cave is located on the Akrotiri Lava formations and two more on Gavrilos hill (Figures 31 and 15) [AQ4]. All of the caves presented some kind of human activity, dating from the prehistoric era to the present day.

Figure 3. (a) A standing drystack wall with ashlar style blocks at Foinikia 2. (b) The interior of the first chamber at Foinikia 2. (c) The interior of Foinikia 1. (d) The entrance of Foinikia 1.



Table 2. A full list of the Santorini cave sites to date with their archaeological potential.

Cave Name	Location	Entrance orientation	altitude (masl)	Deposits Classification	Non-modern Standing Structures	Surface finds density (finds/sqm)	Archaeological Potentiality	Ethnographic significance
Foinikia 3	Kera Panagia Foinikias	W	38	Proven High	Y	0.36	Very High	Very High
Foinikia 2	Kera Panagia Foinikias	W	32	Moderate	Y	0.19	Very High	Very High
Ancient Thera	Ancient Thera	NW	277	High	N	0.61	Very High	Very High
Zoodochos Pigi 1	Kamari	E	242	Moderate	Y	0	High	Very High
Zoodochos Pigi 2	Kamari	SE	252	Moderate	N	0	High	Very High
Vlychada	Exomitis	SE	18	High	N	0.1	Moderate	High
Foinikia 1	Kera Panagia Foinikias	W	22	High	N	0	Moderate	Low
Agios Georgios Katifio	Exo Gonia	N	189	Moderate	Y	0	Moderate	High
Panayia Katifiani	Perissa	S	184	Low	Y	0	Moderate	Very High
Klasoysterna	Profitis Ilias	S	393	Low	N	0	Low	Very High
Gavrilos	Emporio	E	40	Low	N	0	Low	High
Rockshelter at Kokkini	Akrotiri	SE	17	Low	N	0	Low	Low

#### **Caves of Mesa Vouno/Profitis Ilias massif**

The area of Mesa Vouno/Profitis Ilias is the only large, extended limestone area on the island. Caves in this area represent typical karstic formations in the limestone of the Attico-Cycladic massif. On the northern side of the mountain overlooking Kamari Bay, the caves of Zoodochos Pigi 1 (ZP1), Zoodochos Pigi 2 (ZP2), Agios Georgios Katifio (AGK), Klasoysterna, and the Ancient Thera cavity (AT) were recorded (Figure 2 and 45).

Figure 4. (a) The small building in Foinikia 3. (b) Detail of the ashlar style blocks from Foinikia 3. The characteristics of an ashlar block are obvious. The elaboration of the individual block where the only surface of the stone that is fully dressed is the face, while all other sides are roughly dressed. The final shape of the stone is roughly reminiscent of a pyramid. (c and d) views of the stone-built passage-way entrance of Foinikia 3.



1. Ancient Thera cavity (AT). The AT cavity is accessed just off the main path to the Classical-era site of Ancient Thera, by continuing around the cliff face. The entrance to the cavity is very open, surrounded by a man-made dry wall, approximately 2 m high at the northwest corner of the cave entrance (Figure 8). The cave itself is 9.47 m long and was filled with debris from the nearby site of Ancient Thera. Fresh animal dung and the drywall indicate the use of the cave as a herding pen in recent years. Surface survey recorded 24 pottery sherds and three obsidian flakes.
2. Zoodochos Pigi 1 (ZP1). ZP1 is located on the path that connects Kamari with Ancient Thera, just before the built staircase turns to a small, goat path. Zoodochos Pigi 2 is located approximately 50 m to the north. The cave is accessed from a path off the road to Ancient Thera and is adjacent to a small chapel. This has a small curved courtyard (12 × 10 m approximately) with surrounding benches, approximately 30 cm and 70 cm off the ground (Figure 9). The cave entrance is to the left of the chapel; some modern litter and domestic equipment are stored in a small cavity just inside the entrance. Following this there is a man-made hallway and dining area made from stone and plaster. Further inside is a sloping shelf to the left, starting at approximately 1 m in height. Speleothems have formed on the ceiling, which gets lower as the cave progresses. There are several pools of running spring water (gours) at the far side of the cave, which run down into a second small chamber. The lowest part of the cave is approximately 1.6 m, while the highest is approximately 3 m. Several pottery sherds from the Late Classical and Hellenistic periods were recorded, linking the cave with ritual activities during these periods (see Danezis 2001; Demaria 2001). It is difficult to date the chapel, but historical sources suggest that it was built at the beginning of the nineteenth century (Demaria 2001).
3. Zoodochos Pigi 2 (ZP2). ZP2 is located 50 m to the north of ZP1. The entrance of the cave is southeast-facing and approximately 6.5 m in height. The entrance is accessed by climbing up from the public footpath that connects Kamari with Ancient Thera and proceeding through a metal wire gate. The cave itself is the largest natural cave recorded on the island to date, with three large chambers and two long passages. The first chamber is easily accessed, with a large drywall surrounding the east toward the south corner. The first main chamber is largely filled with animal



dung, having been used as an animal pen until recently. The second chamber is located through an eastern entrance and continues far back in a northern direction. Up a slope, the third chamber is reached. The passage through to the third chamber is approximately 5 m and very narrow, such that it requires crawling. The thick layers of animal dung made the location of any archaeological remains impossible to identify from the surface. However, we did find a small grinding stone close to the entrance and against the western wall.

### **Caves in the Foinikia Lava formations/Kera Panagia area**

Three caves were recorded at the Foinikia lava formations, close to the small monastery of Kera Panagia Chochli-deri. All three caves formed in lava and due to their formation are suspected primary lava caves/lava tubes. However, further analysis of the geology of the caves is needed, in order to clarify their speleogenesis.

- 1. (d) Foinikia 1 The entrance to Foinikia 1 (Figure 53) is approximately 200 m from the road, located beneath a west-facing ridge. It is approximately 100 m from a nearby abandoned house (which lies to the south west). The entrance to the cave is triangular in shape, with its top point being approximately 2 m high. The decline into the chamber is approximately 30° on loose reddish-brown soil. In total, the cave is around 80 m long and 20 m wide and, at its lowest point, 15 m high.
- 2. (e) Foinikia 2 The Foinikia 2 (Figure 56) cave is located around 50 m away, following a stone paved pathway going west from Foinikia 1. The cave entrance is 1.35 m wide and 1.7 m tall at the base end, followed by a narrow, 3 m corridor. The inner chamber is approximately 30 m long and 20 m/15 m wide. The main chamber, after the entrance, is surrounded by dry walls made with larger stone blocks. The lower part of these walls is plastered. At the north side a narrow and low passage over the wall leads to a small chamber where pottery sherds dating to the Hellenistic and Roman periods were found. From the second chamber, a 3.5 m shaft leads to a third one where dry wall, with a maximum height of 2.4 m, covers the western side. Twenty-four pottery sherds dating from the post-Classical to post-medieval periods were also recorded at this location.
- 3. (f) Foinikia 3 The Foinikia 3 cave (Figure 4 and 67) is accessed through a narrow passage approximately 1 m wide, 2 m long and 1 m high (1 × 1 × 2) facing west. At the entrance stands a dry wall made from large stone blocks. The main chamber is approximately 20 m long and 15 m wide. In the main chamber, against the northern wall, the remains of a rectangular structure are still standing. This structure was built on the foundations of an earlier structure and it overlaps with an older cistern carved into the bedrock. At the end of the main chamber, in its eastern corner, there is a small 1 × 1 m circular silo/well that has been partially filled by modern debris and soil. The rear part of the main chamber presents another dry wall, which survives to a maximum height of 2.2 m. Foinikia has thick undisturbed deposits that are likely archaeological according to Dinnis et al.'s (2010) classification. At the south side of the main chamber, Bronze Age to post-Medieval surface pottery sherds were collected.

Figure 5. (a) A contemporary pen at Santorini. (b) The Gavrilos rock shelter. (c) The small cavity at Kokkini (Red) beach. (d) The stone built medieval cistern at Panayia Katifiani. (e) The entrance of Klasoysterna with the modern stone built dry wall.



Figure 6. The survey map of Foinikia 2. With gray the ashlar style dry walls. On the right map, the survey units are presented and the findspots are noted in green. Each dot corresponds to a single pottery sherd.

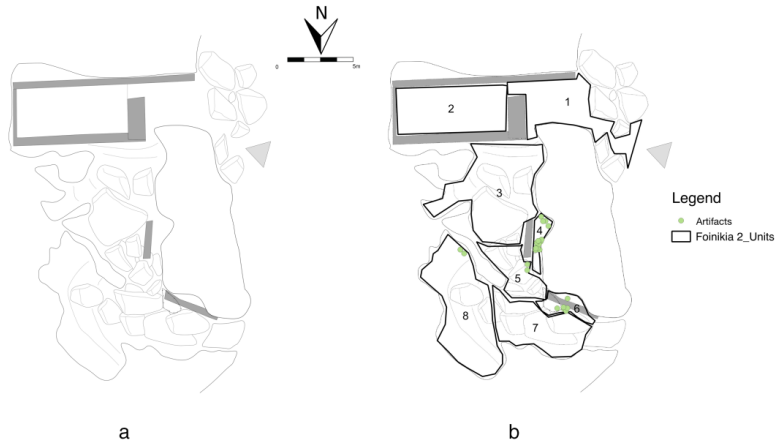
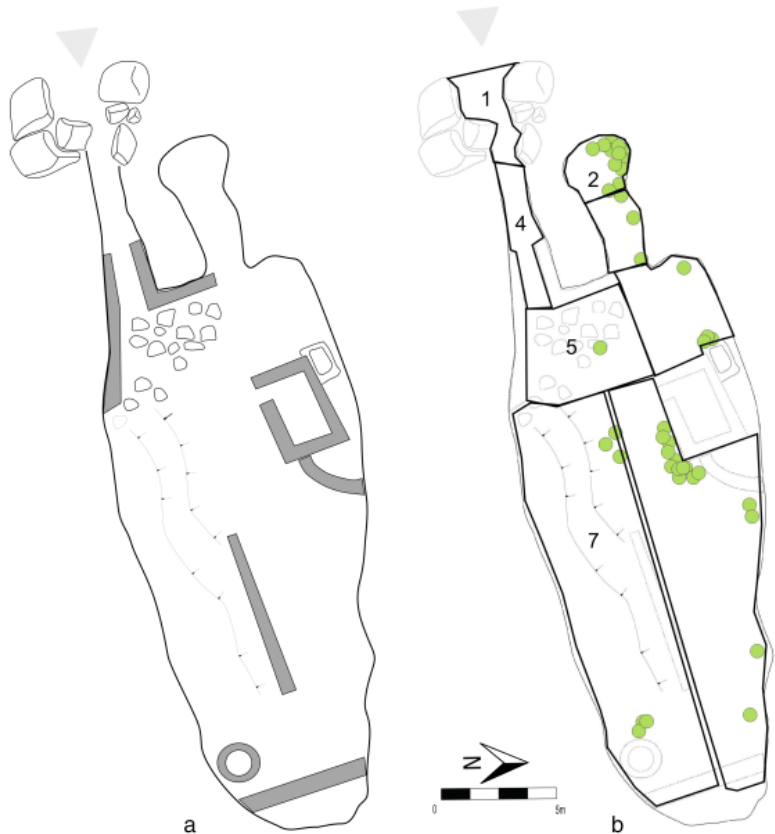


Figure 7. The survey map of Foinikia 3. The ashlar style dry walls are noted in gray. On the right map, the survey units are shown and with finds noted in green. Each dot corresponds to a single pottery sherd.



### ***The remaining sites***

The cave of Agios Georgios Katifio (AGK) on the northern side of the Profitis Ilias massif was initially recorded by the HSS expedition in 1970. During our visits no surface pottery was recorded. However, the prominence of the cave, the intact deposits, and the man-made wall which stands across the entrance, support the theory that locals used the cave as shelter during pirate raids in the post-Medieval era (see Danezis 2001). The rockshelter of Panagia Kati-fiani (PK) is located at the southern side of Mesa Vouno, just off the path to Ancient Thera. The wide rock shelter hosts a small chapel and a cistern that dates to the Venetian period based on the style of building technique and plas-

tering (see (Georgopoulou 2001) Georgopoulou 2001; Kalliga 1997). Some modern pottery sherds were recorded, but no intact deposits of high archaeological potential were identified, following the framework of Dinnis et al. (2010 2001). The cistern is a cavity at the eastern part of the complex, which has been formed into a reservoir for water collection with a stone wall and hydraulic lime plaster. The cave itself is a small inlet with a secondary triangular-shaped window, located 0.5 m up the wall. The cave interior measures roughly 2 m in length and 1 m in width, and boulders cover the floor. An additional wall can also be seen at the rear part of the inlet. The south facing wall is built out of a series of smaller stones encased in mortar, and five or six larger rocks that are used for the edge of the entrance window between two slate slabs. Outside of the cave there is an overhang running for about 6 m to the western side and another man-made wall following the natural curve between the cave and the eastern cliff face. The Panagia Katifiani rock shelter, similar to Agios Georgios Katifio, was used as a shelter during the post-Medieval era (see Denezis 2001).

The two rock shelters on Gavrilos Hill also contain evidence of use as herding pens (low dry walls that block the entrance, modern pottery sherds); however, their deposits are thin (in the case of the Vlychada rock shelter) or absent (in the case of Emporio).

The Klasoysteria cave, close to the Profitis Ilias monastery was also used as a herding pen until recently. The cave deposits were excavated, in order to provide more space for the animals. At the periphery of the cave, however, the few handmade pottery sherds recorded could belong to the Late Neolithic period.

## Results

Of Santorini's 12 recorded natural cave sites, 11 offer evidence of human use in different periods. However, only seven presented surface finds. In the rest, human activities are identified only by standing structures. Of the seven caves with surface finds, in ZP1 and Panagia Katifiani finds are very heavily disturbed by several factors, mainly due to the continuous use of these caves for Orthodox cult practices up to the present day. ZP 2 showcased only one surface find, a hand grinding stone, and the rest of the site is heavily bioturbated due to the use of the cave as a herding pen. Any earlier use has been buried under thick layers of animal dung. Foinikia 1 presented a large amount of contemporary debris at the entrance, and only one hand grinding stone (as in ZP 2) that dates to antiquity. A thick layer of volcanic material, mainly pumice, is present, masking the deposits of the cave and making any archaeological evaluation quite difficult.

Therefore, only the caves of Foinikia 2 and 3 (Figures 8 and 9), Ancient Thera (Figure 10), and the Vlychada rock shelter presented substantial distributions of surface finds that could be recorded and evaluated spatially. Most of the pottery finds in AT are relatively modern and associated with the use of the cavity as a herding pen. However, in AT, against the southern wall of the cavity, three obsidian flakes were recorded that might indicate usage of the cave in prehistory.

Figure 8. The survey map of the Ancient Thera rock shelter. On the right map, the survey units are shown with finds noted in purple. Each dot corresponds to a single pottery sherd. The location of obsidian flakes are highlighted with a white circle.

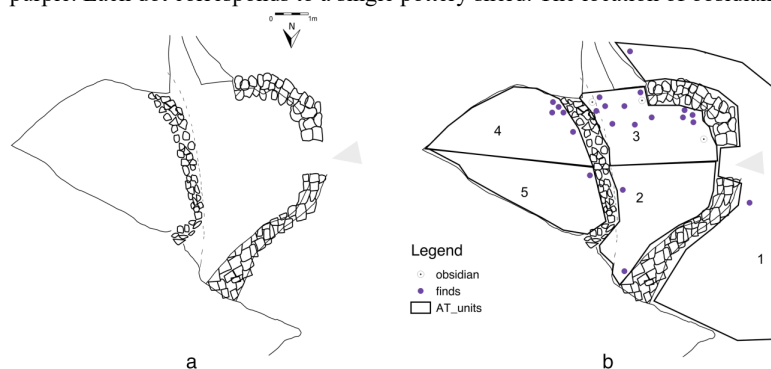


Figure 9. (a) South elevation of the Zoodochos Pigi 1 chapel. (b) The ground plan of Zoodochos Pigi 1 chapel. (c) Elevation of the cistern at Panagia Katifiani.

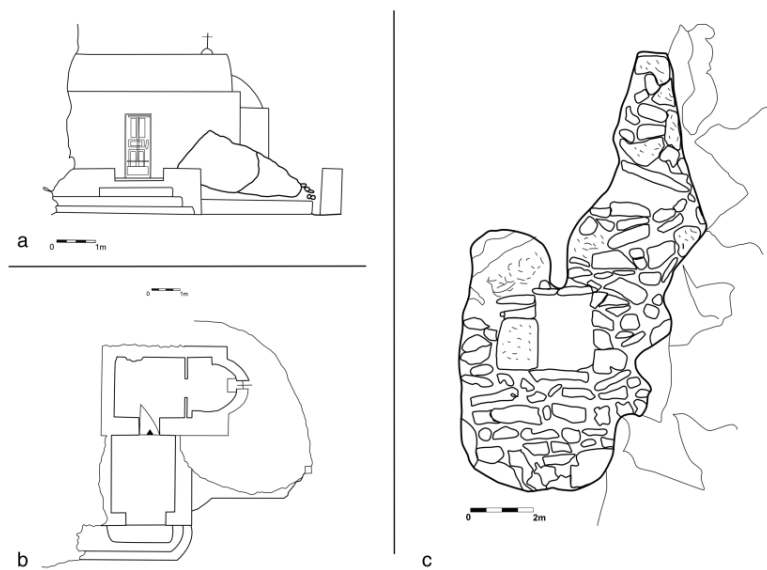


Figure 10. Handmade pottery sherds seen at the Klasoysterna plateau are shown on the left. Hand grinding (rubber) stone from Zoodochos Pigi 2 (top right); grinding stone from Foinikia 1 (bottom right).



Foinikia 3 showcases a slightly higher surface pottery density compared to Foinikia 2, but we need to keep in mind that the latter is far more accessible than the former, making the cave more susceptible to modern-day visitors. In both caves, intra-site densities presented an interesting pattern. The areas with the highest pottery densities are area 2 in Foinikia 2 and area 4 in Foinikia 3. These areas are relatively small and very confined places, where access is very difficult, particularly in Foinikia 2 where the construction of a dry-wall restrains access to the small niche. Most of the pottery in both caves is late Classical Roman with three Venetian sherds present in area 6 in Foinikia 3. One possible Late Cycladic (Late Bronze Age) pottery sherd from Foinikia 3 was recorded, again from area 2.

As also noted in the cases of the Kastoria and Kythera caves (see Trimmis [2013](#), [2015b](#)) on Santorini, the cave surface artifacts are not recorded close to the cave entrances. Even in the case of small rock shelters such as AT or Vlychada, surface artifacts tend to be located away from the cave's entrance arch and closer to the side and back



walls. The phenomenon is more interesting in the Foinikia caves where the majority of the finds are located in the most confined spaces of the caves. We are still uncertain, particularly for the AT and Vlychada caves, if avoiding the entrance of the cave is a deliberate practice or a biased view that we perceive today from the distribution of the finds. However, minimal research on Neolithic cave sites in the Western Balkans revealed that people tended to avoid the entrance areas, as these parts of the caves are more exposed (Trimmis 2019). It could be the same on Santorini, but further research is needed to test this hypothesis.

In the restricted area of Santorini, any analysis on cave entrance orientation or cave altitude in correlation with usage type—as performed by the Mount Pelion project (see Andreasen et al. 2017)—was not applicable. This is because the caves that have been included demonstrate how almost all of the island's cavities were, and still are, used for a variety of purposes, thus making a single-use comparison impossible. As has been observed on the island of Kythera (Trimmis 2015b), two types of cave use dominate the sample; cave chapels and herding pens. On Santorini there are also caves that were used as places for water collection—exclusively so in the case of the PK cavity—a use that was expected, keeping in mind how limited natural water resources on the island are (Figure 11). Overall, two cave chapels (ZP 1 and PK), five herding pen caves (AT, Vlychada, Klasoysterna, Gavrilos and ZP 2), and five caves with water collection installations (ZP 1, Klasoysterna, Foinikia 3, PK and AGK) have been recorded to date, and we still need to identify the use of Foinikia 1 and 2.

## Discussion

The survey of Santorini Island caves, was the first systematic archaeological account of diachronic cave use on an Aegean island and only one of the few globally, along with similar systematic surveys on Easter Island (Jan Ryn 2012), Isla de Mona in the Caribbean (Cooper et al. 2016), and Hawai'i (Kempe and Ketz-Kempe 1997). Unique to the Santorini project, however, is the systematic survey approach employed here, which was built on previous archaeological survey efforts in caves coupled with the presentation of results beyond basic observations and descriptions of any archaeological evidence. Particularly in the Aegean, Santorini is very important for understanding inter- and intra-island dynamics during the Bronze Age, and this project may lead the way for the application of similar holistic approaches to other island environments, including caves and subterranean spaces, as well as any landscape archaeology research. As the main outcome of our evaluation, we note that the natural caves of Santorini were used diachronically as places for animal penning, Christian cult practices, and as shelters during periods of turbulence. These prehistoric to contemporary uses are very common for Greek caves and were observed and discussed in detail early in the context of Crete and the South Aegean by Paul Faure (1964), and later by the Pelion Project (see Andreasen et al. 2017). The pattern of Medieval, modern, and contemporary usage of caves on Santorini is very similar to the other Cycladic islands (e.g., Mavridis, Tankosić, and Kotsonas 2018 for Herakleia and Mavridis 2009 for Antiparos), and also to islands that are not in the Cycladic complex, but that were under Minoan influence earlier and Venetian rule later such as Kythera or Crete (see Trimmis 2015a, 2015b).

The most interesting finding of our survey was the discovery of layers of volcanic material that cover most of the cave paleodeposits. As a result, it is equally difficult to discuss human-landscape interaction in caves as it is for the island's open landscape. At the same time, the distribution of volcanic deposits in caves could provide some insights into how the eruption unfolded (e.g., wind direction, force, materials from volcanic deposition sequence in the geological stratigraphy of the caves). Studies on volcanic material deposition processes have been undertaken in other micro-landscapes of the island like the limestone mountain of Profitis Ilias, but not in caves so far. Excluding the obsidian flakes in AT, the few Cycladic (Bronze Age) pottery sherds from Foinikia 3 and the few handmade pottery sherds in Klasoysterna's periphery (Figure 10+12), the pottery that was recorded in Santorini's caves is exclusively Classical/Hellenistic and Post Medieval/Modern. Assumptions that caves, such as the cavity at Red Beach, might host Bronze Age material (see Vlachopoulos and Zorzos 2014) cannot be verified, however, due to the volume of volcanic material at these caves.

Animal penning in caves is not exclusive to Santorini. Caves in southeast Europe were used as barns or pastoral shelters beginning in the Neolithic period (Trantalidou, Belegriinou, and Andreasen 2010), with similar patterns of spatial arrangements as those seen today (see Andreasen, Pantzou, and Papadopoulos 2009). A drywall that blocks the entrance of the cavity and smaller partition walls in the interior of the cave are the most common pattern in the Aegean (see Trantalidou, Belegriinou, and Andreasen 2010; Trimmis 2015b). ZP 2, AT, and the Vlychada rock shelter are the best examples on Santorini, particularly ZP 2 as the cave was used until recently and the dry walls remain



standing at their full height. Animal herding is still an important part of the island's economy today, even though intensive development has destroyed most of the traditional pens. Zooarchaeological data from Akrotiri, along with the image of a pen in the famous "ship procession" fresco found at Akrotiri (see Trantalidou 2008), highlights the importance of animal herding for the Bronze Age island's society. A modern-day traditional pen that was photographed during our survey looks very similar to the pen that is depicted in the fresco. Maybe the limestone cavities of the island were used in a similar way; however, bioturbation, speleoapothosis, and taphonomic factors were an obstacle for recording such activities in our survey. Due to significant taphonomic processes in herding pen caves, such as in the caves that were filled in by volcanic material, we recorded very few surface finds. This may also be due to the large volume of dung deposited in the sites.

The caves with the highest archaeological potential are, by far, the three caves in the Foinikia area. Foinikia 1 is, to a large extent filled in with volcanic material, which made it impossible to record surface pottery. However, in areas inside the cave, clear intact deposits with high archaeological potentiality were recorded. Foinikia 2 and especially Foinikia 3 are the most interesting sites of the group with their walls and standing structures. Foinikia 3 also has the greatest pottery density of all of the cave sites on the island. In Foinikia 2, the lower parts of the wall are covered by a layer of white plaster. Stereoscopic examination of a plaster fragment in the laboratory of Santorini's Museum of Prehistoric Thera, confirmed that the plaster is not hydraulic and very similar to the contemporary lime plasters that people on Santorini use for their lime-washed houses. This adds to the oral information collected from Foinikia village inhabitants that Foinikia 2 has been used as a storage facility by local farmers and minimizes the possibility that the walls are part of a post-medieval cistern. The building techniques of the Foinikia 2 and 3 megalithic dry walls are similar, though macroscopic observation links these to the LBA ashlar walls of Akrotiri. Palyvou (2005, 116) describes the ashlar walls of Akrotiri (and the Aegean in general) as having the following common features: 1) elaboration of the individual block: the only surface of the stone that is fully dressed is the face, with all other sides being roughly dressed; 2) the final shape of the stone is roughly reminiscent of a pyramid: all sides but the face are slanted so as to facilitate the structure. The upper and lower surfaces are only slightly slanted, but the other two sides form acute angles; 3) how round the backside is may showcase different phases of the dressing techniques (Figure 6B). From our survey, at least the southern wall in Foinikia 2 and the eastern wall in Foinikia 3 (and possibly the passage) seem to have been constructed following these patterns. Similar stone structures, but without the state of preservation found in the Foinikia caves, were recorded in several caves on Crete (such as Amnisos, Skoteino, Melidoni; for an overview see (Rutkowski and Nowicki 1996) Rutkowski and Nowicki 1996) and Kythera (Kataphygadi; see (Trantalidou et al. 2019) Trantalidou et al. 2019) and securely dated to the Bronze Age. All of these cases have been named 'spiritual' cave sites organized for Minoan (Bronze Age) cults. However, in these examples, the remaining structures are too small or derelict to be strictly analogous with the Santorini caves that contain constructed walls. Additional evidence supporting the antiquity of the Foinikia walls is that similar to Foinikia are the structures from Ellinokamara cave on Kassos island, southeast of Santorini, but still in the Cretan periphery. The walls in Ellinokamara have been dated securely to the fifth century BCE based on results garnered from the long-standing excavation program by the Ephoreia of Paleoanthropology and Speleology (see (Sakellarakis 1988). Sakellarakis 1984). Occupation in Ellinokamara is dated even before the construction of the fifth century walls, as early as the EBA, which may also support an earlier occupation in Foinikia. An archaeological evaluation at the Foinikia caves, which is planned to take place in the near future, may confirm or reject this hypothesis and the dating of these walls to either the LBA or to Classical antiquity.

Other than the Foinikia 3 structures and Foinikia 2's northern walls, smaller stacked stones (drystack) are the main building material for the structures in the caves. Drystack is the main building technique for the buildings of Akrotiri (and for other LBA sites such as Raos; see Palyvou 2005). However, since drystack with medium size angular stones remains the primary building technique for all dry walls on Santorini, it is very difficult to date these structures based on the building technique alone. What we can observe is that in the Foinikia caves, there are different phases of structure construction, with the megalithic "ashlar style" walls assumed to date to the LBA and the drystack walls to later periods. However, further research on the structures and the archaeological deposits may offer a better understanding of the Foinikia caves.

To refer to Mlekuž's theory of cave affordances (2012), Santorini's caves offered people living on the island certain kinds of resources that the volcanic environment lacked, such as freshwater (Caves of ZP 1 and Katifiani) and safe shelter. Through time, people on Santorini chose how they were going to use a cavity based on the microenvironment. Thus, ZP 1, with its freshwater spring, became a community space and was organized as a chapel dedicated to

“life-giving water” (is what ‘Zoodochos Pigi’ translates to English). Alternatively, the large and dry cave of ZP 2 became a pen, as the cave can protect and hold a large number of animals. Caves are not the only way to understand the deliberate attention that people paid to their natural environment’s characteristics. The way that they used the island’s microclimate to dry-cultivate grapes and pulses is another good example of the knowledge that locals had and still have about their microenvironment (Vavoulidou et al. 2006).

Comparing the preliminary outcomes from the cave survey on Santorini, with the available information from the Mount Pelion caves project on the Greek mainland (see Andreasen et al. 2017), we find that caves are indeed marginal places that lie on the periphery of primary settlements. At the same time, they are sites at the center of people’s lives (Mavridis 2015, 2018b). Locals have extensive knowledge about caves and what each of them can offer. What has been shown from an ethnographic overview of Kythera Island’s caves (see Trimmis 2015b) is that these affordances equally shape people’s perceptions about caves and the landscape; caves with water, for example, are usually perceived as “sacred” spaces and the water as “holy.” On Santorini, some of the sites are still used today for various activities, such as the cave chapels of Zoodochos Pigi and Panagia Katifiani. People gather at these sites twice a year to celebrate the chapel and then have a communal feast at the cave’s entrance. As Mavridis and Tae Jensen (2013) proposed, caves and other natural locations that have been transformed by humans into cultural constructs are shaped by myths and traditions and, therefore, are invested with social meaning and significance. Our research on Santorini showcases the significance the caves had and still have for locals, as well as their potential for archaeological and ethnographic research on the diachronic relationship between Cycladic peoples and their island landscapes.

The majority of studies conducted on small island environments demonstrate that peoples have an archipelagic point-of-view and see inter-island relationships as an essential part of living on them while recognizing that they are also surrounded by a natural aquatic boundary (see Rainbird 2007; Fitzpatrick et al. 2016). Intra-island studies are focused mainly on larger island massifs (such as the case in Malta and Sardinia; Skeates 2011) or on isolated islands with great archaeological significance (such as the case of Easter Island; see Jan Ryn 2012).

Projecting this paper’s outcome, it becomes apparent that in the small available land of an island setting, particular topographic features such as caves are important since they are embedded with meaning and significance by people (see for example Buxton 1994, 90–113). They can be considered as “marginal” areas within a “marginal” (small island) world, that they yet still play a “central” role in people’s lives.

Societies may even connect to neighboring islands, as is the case of Agios Ioannis cave on Herakleia island, for example, when pilgrims from the rest of the Cyclades visit this site on St. John’s day to pray and celebrate (Mavridis, Tankosić, and Kotsonas 2018). On Santorini, the examples of Panagia Katifiani, and Zoodochos Pigi 1 further support this notion when people from Therassia, Ios, and Anafi Islands sail to Santorini to participate in the celebrations on Zoodochos Pigi day in the homonymous cave. In other words, cave use on Santorini and the Cyclades seems to follow Patton’s (1996, 188) view on insular dynamics where island landscapes in a core/periphery model seem to work by default as both.

The Santorini fieldwork demonstrates that caves in small island environments may be used in the same ways as caves on the mainland or larger islands, but have a different and more prominent position in the lifeways of people who live on the island as well as outsiders. Our survey of Santorini’s caves reveals that the caves played, and continue to play, a significant role for the island’s society. From places of shelter and water collection in Medieval times to modern day animal pens and places for congregation, Santorini’s caves are an important case study for understanding insular dynamics—and landscape exploitation—in the post-medieval Eastern Mediterranean. All three Foinikia caves are still a major puzzle, not only because of their wealth in surface pottery, but primarily because of the large standing walls and the complexity of the structures in Foinikia 3. The absence of any information in the relevant literature about the building of these structures during the Venetian or Ottoman periods, and the similarity of the building techniques with the Akrotiri ashlar walls, leaves open their age and interpretation. In addition, from a methodological perspective, the Santorini Project demonstrates that a combined approach that incorporates the densities of surface finds with the geomorphological characteristics of the caves and the evaluation of their deposits, offers a firm ground for multidisciplinary interpretations of the biography of cave sites. These biographies can then be developed further and combined with analytical data to provide hard evidence for more in-depth and theoretically nuanced interpretations.

Table 1. An explanation of the classification of *archaeological potential* of cave deposits (according to Dinnis, Davies, and Chamberlain 2010, 46).

Deposits Classification	
Proven High	Sites with excavated or undisturbed sedimentary deposits that have been demonstrated to contain material of archaeological importance
High	Sites with in situ sedimentary deposits of sufficient volume and appropriate composition that they are very likely to contain important archaeological evidence
Moderate	Sites with in situ sedimentary deposits that may prove on further investigation to be favorable to the preservation of archaeological remains
Low	Sites with deposits that are likely to be sterile, or of such recent depositional origin that they are unlikely to yield finds of archaeological significance

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Sequence	Prefix	Given name(s)	Surname	Suffix
1		F.	Mavridis	
2		K. P.	Trimmis	

**Author Response:** Ok

**Production Editor Response:** Ok

**Query:** AQ1: The article title mismatches with the cats and manuscript. Thus we have followed the manuscript. Please check and revise if incorrect.

**Author Response:** Can we change the island name from 'Thera' to 'Santorini' in the title? Meaning the title will be 'Recording Santorini's subterranean Landscapes'. The island has two names and are equally acceptable. I believe that Santorini is more widely known.

**Production Editor Response:** Answered within text

**Query:** AQ2: Please check whether the author names (first name followed by last name) and affiliations are correct as presented in the proofs.

**Author Response:** Ok

**Production Editor Response:** Ok

**Query:** AQ3: Please confirm whether the correspondence details are OK as typeset.

**Author Response:** Ok

**Production Editor Response:** Ok

**Query:** AQ4: Figures 11, 12, and 15 captions are missing in the text. Please delete the citations or provide the captions.

**Author Response:** Answered within text

**Production Editor Response:** Answered within text

**Query:** AQ5: Please provide complete details for (Ingelese 2008, Dinnis et al. 2001, 2012, 2013, Holderness et al. 2006, Brady 2012, Andreasen et al. 2018, Georgopoulou 2001, Kalliga 1997, Rutkowski and Novicki 1996, Trantalidou et al. 2019, Buxton 1994, Sakellarakis 1984 and Mavridis 2015) in the reference list or delete the citation from the text.

**Author Response:** Answered within text

**Production Editor Response:** Answered within text

**Query:** AQ6: There is no mention of (Broodbank 2013, Doumas 1983, Doumas 1992, Karkanis 2013, Kyparissi-Apostolika 2013, Manning 2014, Marthari 2004, Renfrew 1972, and Warburton 2009) in the text. Please insert a citation in the text or delete the reference as appropriate.

**Author Response:** Answered within text

**Production Editor Response:** Answered within text

**Query:** AQ7: Please provide the publisher name.

**Author Response:** Answered within text

**Production Editor Response:** Ok

**Query:** AQ8: Please provide the conference location.

**Author Response:** The conference location was Paris. However the volume is produced in Liege in Belgium as the title of the publication indicates

**Production Editor Response:** Ok

**Query:** AQ9: Please provide missing citations for Figure 2, Figure 7, and Table 1.

**Author Response:** Answered within text

**Production Editor Response:** Answered within text

## COMMENTS

[C1](#) Production Editor: provide link

[C2](#) Production Editor: provide link

[C3](#) Production Editor: provide link

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